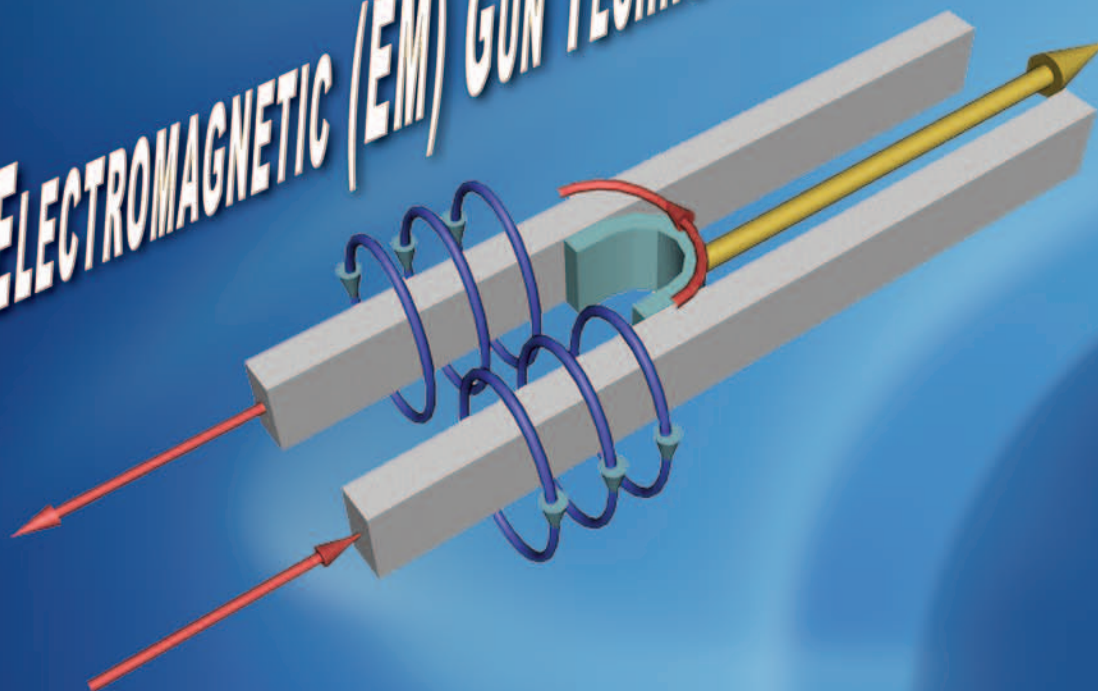


ELECTROMAGNETIC (EM) GUN TECHNOLOGY ASSESSMENT

FEBRUARY 2004



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This report is a product of the United States Naval Research Advisory Committee (NRAC) Panel on Electromagnetic (EM) Gun Technology Assessment. Statements, opinions, recommendations, and/or conclusions contained in this report are those of the NRAC Panel and do not necessarily represent the official position of the United States Navy and United States Marine Corps, or the Department of Defense.

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14. ABSTRACT <p>The Naval Research Advisory Committee was asked in May 2003 to conduct an assessment of the current maturity of electromagnetic (EM) gun technology for the Assistant Secretary of the Navy (Research, Development & Acquisition). Specifically, the Committee was tasked to: review and assess the technical and operational performance capabilities necessary to achieve a militarily effective EM gun system for naval application; review the current and anticipated state of the technology and provide an assessment of the performance, manufacturability and maintainability of an EM gun system; and evaluate the technical and developmental risks in producing a projectile that will perform throughout the mission profile, i.e., launch to precision impact on target.</p> <p>The study panel concluded that while there were significant engineering challenges that must be overcome to produce an operational naval EM gun, there were no new technology issues to be solved. Additionally, the study panel provided a strawman roadmap that would enable the Department of the Navy to within four years have sufficient technical basis to decide whether or not to proceed with a development program that could be completed in an additional four years.</p>					
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Naval Research Advisory Committee Report



ELECTROMAGNETIC (EM) GUN TECHNOLOGY ASSESSMENT FEBRUARY 2004

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NAVAL RESEARCH ADVISORY COMMITTEE

Naval Electromagnetic Gun Technology Assessment

**Presentation to
The Honorable John J. Young, Jr.
Assistant Secretary of the Navy
(Research, Development & Acquisition)
9 September 2003**

The Naval Research Advisory Committee (NRAC) was asked to assess the status of electromagnetic (EM) gun technology.

The concept of using EM force to propel a projectile was conceived and demonstrated in the late 1800's, in Norway. Although this was an interesting concept, conventional gunpowder was also an available, acceptable way to satisfy military needs. This has held true until recent times.

Today, we have made our forces lighter and are moving them deeper into enemy territory. We have made them lighter by reducing their lethal firepower; a concept that increases the importance of fire from the sea. However, going deeper has taken us beyond the range of conventional guns. The remaining options are missiles and tactical air support which are costly and limited by weather.

EM guns have the potential to deliver lethal firepower to ranges in excess of 200 nautical miles (nm). The decision to develop the destroyer of the future (DD(X)) as an all electric warship will result in a platform with more than sufficient power to support an EM gun.

The question we have been asked to address is: Is EM gun technology mature enough to be considered for DD(X)?

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Terms of Reference

- A. Review and assess the technical and operational performance capabilities necessary to achieve a militarily effective EM gun system for naval applications
- B. Review the current and anticipated state of the technology and provide an assessment of the performance, manufacturability and maintainability of an EM gun system
- C. Evaluate the technical and developmental risks in producing a projectile that will perform throughout the mission profile, i.e., launch to precision impact on target
- D. Provide a ROM for non-recurring gun and projectile technical development, operational gun maintenance and projectile recurring acquisition costs

Naval Research Advisory Committee

EM guns can be effective in a variety of Naval applications, from Naval surface fire support to ship defense. Our study considered this range of applications, but we focused on the surface fire support mission and the performance effective fire support requires. We chose to do so because EM gun technology appeared most disruptive when applied to this mission.

We assessed the state of the technology required to achieve desirable performance levels. We lacked both time and information to dwell on manufacturing or maintainability, but do not consider either of these to be a major concern.

The study does address the risks of producing a projectile (which we conclude must be guided). There are concerns here, but we believe the plan we propose will permit their early resolution.

We developed a ROM for technical development in two phases: an immediate short-term effort that addresses the “critical” technical issues and permits early informed decisions; and a second phase that results in development and demonstration of a full-scale system.

Note: A complete Terms of Reference can be found at Appendix (A)

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Panel Membership

- **Mr. John “Jack” Bachkosky – Chair (Systems Planning Corporation)**
- **Mr. Richard “Dick” Rumpf (Rumpf Associates International)**
- **VADM Douglas Katz, USN (Ret.) (Consultant)**
- **Professor William Weldon (University of Texas at Austin)**

CAPT Dennis Ryan, USN (Ret.) - Executive Secretary

Naval Research Advisory Committee

VADM Doug Katz is a Surface Warfare Officer with considerable experience and expertise in combatant ship operations, capabilities and concerns.

Professor Bill Weldon is a recognized technical expert in EM guns and associated technologies.

Dick Rumpf is a former Acting ASN (RD&A), a recognized expert in high performance rocket and air breathing missile systems design and testing.

Capt Dennis Ryan was a Surface Combatant Commanding Officer and adds another element of operational experience.

Mr. John Bachkosky has been involved in electrothermal, chemical, and EM gun development and testing, as well as hypervelocity impact and lethality issues.

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Approach

TOR: 5 June 2003

Panel Assembled: 17 June 2003

Visit: EM Gun Facility: Kirkcudbright, Scotland 23 June 2003

Briefings: 6-9 July 2003

- Navy - PEO SHIPS, NAVSEA, ONR, NSWC Dahlgren, CNA, ONI
- USMC - MCCDC
- Army - IRT, ARL, IAT
- Industry - United Defense, Lockheed Martin, SAIC, GA
- Other - DARPA, CEM-UT, Sandia
- Reviewed Briefing Materials, Past Studies

Analysis, Discussions, Conclusions, Recommendations: 21-30 July

Naval Research Advisory Committee

We were asked to do this study on 5 June 2003, and the panel had assembled by 17 June 2003. We began by discussing our approach, and by identifying reports and data we wanted to review, briefings we needed to hear, and installations we hoped to visit.

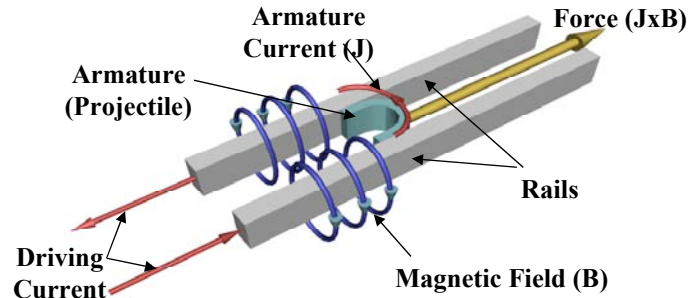
Half of the group was able to visit the EM Gun Facility in Scotland.

We received the briefings indicated in early July 2003. They ranged from detailed technical briefings on sabot-projectile designs to discussions of test data and operational needs to programmatic issues and funding.

Finally, we gathered at Space Warfare (SPAWAR) Systems Center (SSC) San Diego analyzed and discussed the information we had gathered, and reached the conclusions we present on page 21.

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Railguns Use EM Force




- ▶ Current flowing in the rails creates a magnetic field which interacts with the current in the armature to generate the propulsive force
- ▶ The gun bore can be round, square or rectangular

Naval Research Advisory Committee

This is a schematic representation of an EM gun. The type shown is a railgun—the most promising technology, as this report will make clear. When a railgun is fired, the current flowing in the rails creates a magnetic field that interacts with the current flowing in the armature—the projectile—to generate propulsive force. A railgun does not burn conventional chemical propellants. The bore of a railgun can be cylindrical, square, or rectangular.

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Electric Gun Types		
Electrothermal Guns	Coilguns	Railguns
Thermodynamic forces	Electromagnetic forces	
Modest launch velocity increment over powder gun	1000 m/s launch velocity demonstrated	2000 to 3000 m/s launch velocity demonstrated regularly
Army MRAAS 105 mm choice	Little research at present	Army 6.1/6.2 & Navy NSFS option
Only the Railgun has demonstrated a hypervelocity capability		

Naval Research Advisory Committee

The panel considered three types of electric gun: railguns, coil guns, and electrothermal guns. Electrothermal guns are the most like conventional guns—they use electricity to control the burn rate of the round propelling charge. The principal attribute of this gun is more uniform acceleration of the round. Since the performance is only marginally better than a conventional gun, electrothermal guns cannot satisfy Naval Surface Fire Support (NSFS) range requirements.

Of the three EM gun concepts, only the railgun has demonstrated launch velocities in the 2 to 3 km/sec range. The coil gun may have potential, but it is far less mature than the railgun. Very little effort has gone into developing coil guns, and in any case this approach appear to lack the railgun’s war fighting or growth potential.

The panel therefore decided to focus this study on the railgun concept. Although railguns have been of interest for some time and many have predicted their potentially revolutionary war-fighting capability, only now are enabling technologies and support systems becoming available.

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Why Now?

**Integrated Power System
Selected for DD(X)**



80MW in 2012

**Progress in Hypersonic
Projectile**



Launch > Mach 6

**Advances in
Railgun Technology**



2.5km/s > 100 Shots

Enabling Technologies for Transformational Naval Railgun

Naval Research Advisory Committee

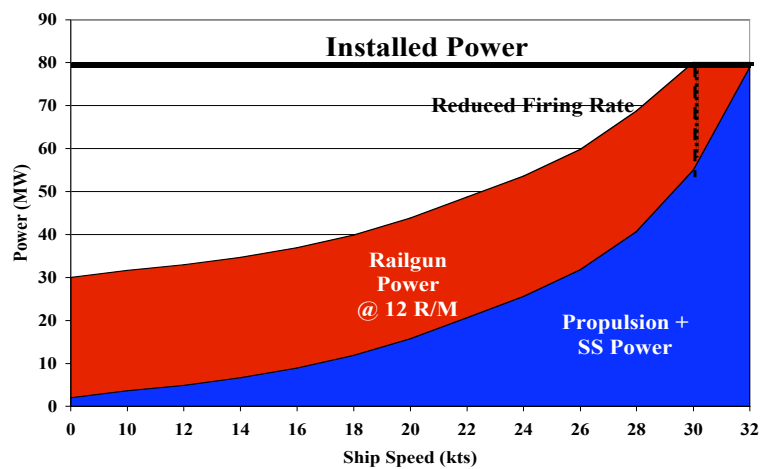
The selection of the Integrated Power System for DD(X) provides the basic power source for a Navy railgun. The 80mw of power available on DD(X) are more than adequate to meet the needs of the Naval railgun and other electromagnetic launch options that might be considered. If we limit our analysis to the weight and volume envelopes allocated to the Advanced Gun System (AGS), we believe that a railgun capable of putting lethal fires on targets more than 200 nm from the ship, and accommodating more than 2400 rounds of non-explosive ammunition can be developed and fielded. Advances in railgun and projectile materials, designs, and guidance capabilities all combine to enable the Navy to achieve this capability. Some issues that have not been resolved, but we are confident that, with a commitment to a structured program and a reasonable investment, these issues will be.

We believe that it is important to future Naval Forces, and our ability to satisfy Sea Power 21 objectives, to commit the resources, funding and personnel, to execute a program like the one our recommendations outline.

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Available Power Vs. Ship Speed (DD(X))



Ship spends 90% of its life below 60% full power

Naval Research Advisory Committee

This chart shows very clearly that under all but flank speed conditions there is more than enough electrical power available to operate the gun. We are also convinced that it would be extremely rare – to the point of not happening – that the DD(X) would be providing Naval Surface Fire Support (NSFS) while moving at speeds greater than 25 knots.

Conclusion is that DD(X) Integrated Propulsion System (IPS) enables consideration and exploitation of railgun technology for NSFS and other applications. It is crucial that these weapon electric loads be considered in the initial design and specification of the DD(X) IPS.

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Findings

Railgun Potentially Revolutionary And Disruptive

Naval surface fires

- Indirect fire
 - Naval surface fire support
- Direct fire
 - Missile defense
 - Anti-ship
 - Asymmetrical/counter-swarm

Technology

- EM capability enabled by electric warship
- Technical risk for other platforms
- Issues -- “Yes, but no known show stoppers”

Programmatic

- Funding inadequate to address issues

Naval Research Advisory Committee

The EM gun is potentially transformational.

Consider the NSFS mission, which involves primarily indirect fire. The EM gun is the only alternative to expensive missiles or Tactical Air if the Fleet is to support the Marines in Ship-to-Objective Maneuver (STOM). STOM requires ranges in excess of 135 nm. No conventional gun can achieve that range. Furthermore, the railgun offers other attractive options. It would permit gunners to select from a new range of warheads appropriate to different target or different missions—cubes for volume fire, a unitary warhead for hard target, kinetic energy kill, etc. It would also increase usable magazine capacity by 3-5 times the number of rounds over what a ship armed with AGS could carry. Railgun ammunition also offers the prospect of simpler and safer handling and storage.

In direct fire applications, including missile defense, anti-ship, and asymmetrical or counter-swarm roles, the railgun should be far more effective than CIWS in terms of projectile pattern and velocity.

Railguns might be able to replace current tank main guns in the anti-armor role, and may prove to be the best answer to reactive armor.

For all these applications, we find that the electric warship is the key enabler. It can provide the power and can easily accommodate the railgun’s weight and volume. With other platforms we find that volume and weight constraints are far more severe. Meeting these constraints, and handling the thermal loads a railgun generates, in a vehicle the size of a tank presents a considerable challenge.

So there are issues surrounding the technology, but we could find no show-stoppers for NSFS or other applications based on the electric warship. We also find that the payoff is significant enough to justify the investment necessary to address the unresolved issues.

While we did not complete a thorough study of manufacturing or maintainability, our preliminary findings indicate no unusual problems in these areas.

Our major concern that the IPS for DD(X) must be directed to include an EM gun in the evolution of its design. The Army, Navy, Defense Advanced Research Project Agency (DARPA), Strategic Defense Initiative Organization/Model Driven Architecture (SDIO/MDA) have all invested in EM technology. What's new is the electric warship. It provides the power and space to accommodate an EM gun: a revolutionary warfighting capability that also increases magazine capacity, improves safety, and reduces costs and logistical requirements. It would be a mistake to pass up this opportunity.

Conclusion

- **A Railgun On An Electric Warship Could Provide:**
 - Revolutionary disruptive warfighting capability
- **This Capability**
 - Can be achieved with technologies that exist but have not been integrated or demonstrated at required levels or as a system
 - Technical risk is moderate
 - Funding and time required to accomplish

Naval Research Advisory Committee

The ability to launch a 15kg projectile at velocities around 2.5 km/sec provides a means to deliver lethal power on target at ranges in excess of 200 nm and at terminal velocities greater than 1.5 km/sec. This coupled with a robust GPS/INS system that we believe is capable of withstanding the launch loads and flight environment will provide a means to deliver lethal volume and precision fire support from the sea to fixed, hard, soft, or mobile targets. With projectile flight times on the order of six minutes, railgun fires will be much more responsive than those delivered by competing systems. EM guns will be able to deliver fire support at much lower cost than any known alternatives, and under all conditions.

We believe that the technologies to achieve this capability exist—many have not been tested at “full scale levels” primarily because the funding or the need to do so was not evident. For example, GPS/INS guidance units have been successfully tested to 28 kgee. There were no signs of failure at this level; there simply was no identified need to go higher. Similarly with EM gun barrels—there have been a limited number of firings on any given barrel. While there has been significant progress in rail materials, sabot-projectiles designs, and other barrel innovations, an effort to clearly demonstrate barrel durability has not been—but must be—executed.

The funding and time required to address these issues are not insignificant. We have developed a funding and schedule plan that we believe is realistic and executable. It is considered to be of moderate risk, both technically and programmatically.

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Railgun Pulsed Power Supply Options

	10 m Railgun	10 m Railgun	AGS Magazine (DD(X) Mt 62)
Pulsed Power Supply	Pulsed Alternators	1.4 j/g Capacitors	
Volume (m ³)	69.6	85.5	788
Weight (kg)	74,121	143,076	193,000

Pulsed alternator is the preferred pulsed power supply

Naval Research Advisory Committee

I would like to briefly discuss the pulsed power supply issue. As indicated on this chart a railgun system capable of the performance levels just discussed could be achieved using either pulsed alternators or capacitors. This chart shows the weight and volume for each of these options, based on current alternator and capacitor technology and compared to that currently allocated for a single AGS magazine. Note that, while there is hope that higher energy density capacitors might be developed, there has been little progress in this area for over ten years. Additional capacitor based power supply issues, such as limits on time-at-charge and degradation due to repetitive operation, remain to be addressed. We regard the pulsed alternator option as the preferred approach.

The inclusion of significant inertial energy storage in rotating electrical machines can beneficially affect IPS stability and enable more energy efficient operating modes.

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Recommended EM Gun Option

- **Pulsed Power Supply – pulsed alternator** (Highest energy density option using demonstrated technology)
- **Projectile – barrage round derivative**
(Aeroballistic design, GPS/INS guidance, kinetic kill)
- **EM Gun – railgun / armature**
(Most mature technology)

Naval Research Advisory Committee

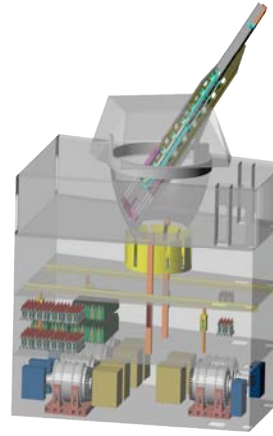
This is the recommended EM gun option. It is the lowest risk approach to achieving a NSFS capability that satisfies the Marine Corps' need to support STOM at ranges of 135 nm and beyond. This option would not only be well-suited to meeting NSFS requirements, but would also provide the foundation for other applications including ship self-defense, UAV launch, and logistics re-supply of forward deployed forces.

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Naval Railgun System Parameters

- Projectile Mass – 15 kg
- Launch Mass – 20 kg
- Launch Velocity – 2.5 km/s
- Muzzle Energy – 63 MJ
- Barrel Length – 10 to 12 m
- Peak Accel. – 45 to 38 kgee's
- Firing Rate – 6 to 12 Rnds/Min
- Power Req - 15 to 30 MW
- Range – > 200 nm
- Kinetic Energy/Target – 17 MJ
(ERGM - 7 MJ, LRLAP - 14 MJ)

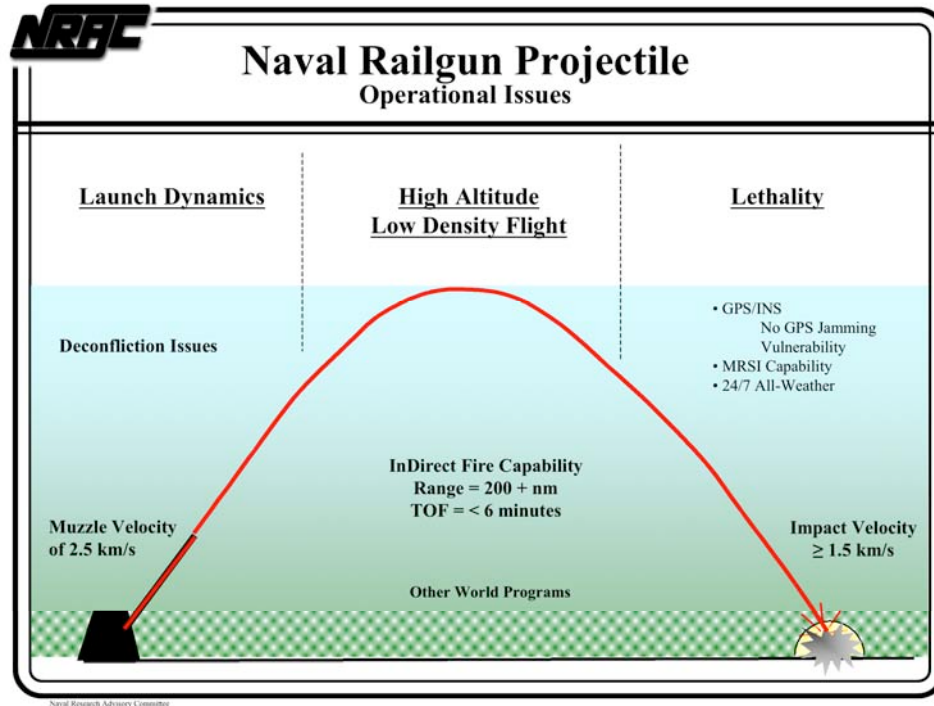


Naval Railgun in DD(X) VLAGS
Footprint

Naval Research Advisory Committee

This artist's concept of the Naval railgun system installed in the AGS envelope shows the space available for increased ammunition storage or other needs. The kinetic energy the hypervelocity projectile delivers to the target is compared to that delivered by conventional weapons. In addition to the delivered energy being higher, it would also be more focused and hence more destructive.

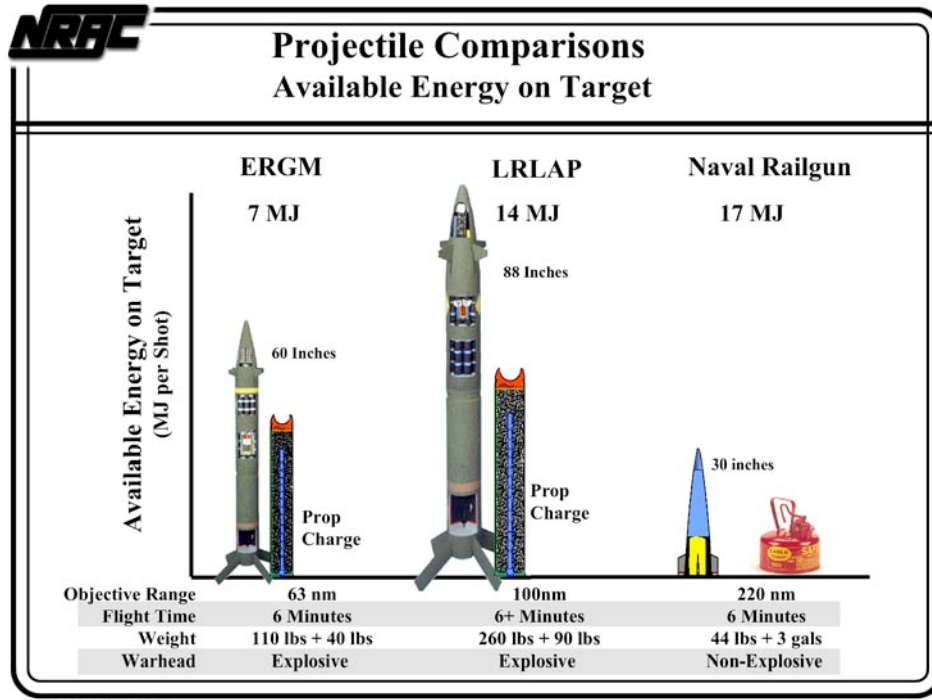
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This chart outlines some of the major advantages of the Naval railgun. Significant are the very short six-minute time of flight, the continuous availability of railgun fires regardless of weather, the difficulty of a target's defeating the kinetic energy projectile, and increased lethality of the projectile itself. The airspace deconfliction issue—a major operational concern with both conventional guns and missiles—is virtually eliminated. Long range conventional guns, rockets and missiles transit through airspace that must be cleared of aircraft. Along its entire path from launch to impact, the railgun's projectile spends only a very short time in usable airspace: immediately after launch and just prior to impact. Railguns pose only a trivial airspace management requirement compared to their alternatives.

Similarly the sensitivity to jamming of the GPS guidance unit with its rear facing antenna is much reduced during the terminal portion of its flight. Launch dynamics and lethality of the kinetic energy projectile are issues that the study panel proposes be addressed early in the development program.

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Compare the characteristics of various projectiles. The railgun's hypervelocity projectile (HVP) is smaller, and so a ship can accommodate about four times as many rounds in its magazine as it could if it were carrying conventional ammunition. The HVP delivers approximately 17 MJ to a target—a highly lethal terminal effect—and it does so at much greater ranges. The HVP is also inert, and so poses no explosive threat to its handlers. HERO, ESD, and cook-off would be unknown, and no unexploded ordnance would be left on the ground after a target was serviced. Similarly, since the railgun uses electric current as opposed to burning propellant to accelerate the projectile, no rocket motors or propellant charges would be required. The cost to launch an HVP amounts to that of about three gallons of fuel.

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Issues

- **Ship Integration**
- **Pulsed Alternator**
- **Projectile**
- **Railgun**

Naval Research Advisory Committee

We address each of these issues in more detail below, but, based on our analysis of the analytical and experimental work that has been done to date, the study panel believes that the technology base exists to develop a railgun that:

- would be compatible with a DD(X)-sized ship,
- could launch a 15kg projectile with a muzzle velocity $> 2\text{km/sec}$,
- could achieve ranges in excess of 200 nm, and
- could deliver kinetic energy projectiles with the precision required to destroy hard fixed targets and mobile soft targets.

The panel also strongly believes that this capability can only be realized by developing and adequately funding, at the earliest opportunity, a program centered around experimental demonstration of required performance and structured to address the remaining critical issues.

The panel believes that in eight years such an effort can be executed and the necessary data obtained to make informed decisions on proceeding with a production decision to allow spiral insertion into DD(X).

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Ship Integration Issues

- **IPS Dynamic Power Management**
(expands DD(X) IPS design)
- **Thermal Management**
(30 MW @ 50% efficiency = 15MW heat rejection)
- **Also**
 - Equipment arrangements
 - Shock resistance
 - Signature - acoustic and EM
 - Personnel safety in an EM environment

Naval Research Advisory Committee

Electromagnetic gun requirements must be considered in the decision and development of IPS. The same consideration applies to handling the 15MW of waste heat that will be generated. The railgun should be located in close proximity to the pulsed alternator to minimize the engineering issues associated with handling 6 MA currents over unduly long cable lengths.

These and the other issues must be addressed, but they are engineering challenges as opposed to new technology issues. All are resolvable.

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Pulsed Alternator Issues

- **Naval railgun rate of fire requires active cooling**
- **Also**
 - **Energy/power density (derisked by Army)**
 - **Alternator size ($\approx 2 \times$ Army)**
 - **Multiple alternator synchronization**
 - **Auxiliary support systems weight/volume**

Naval Research Advisory Committee

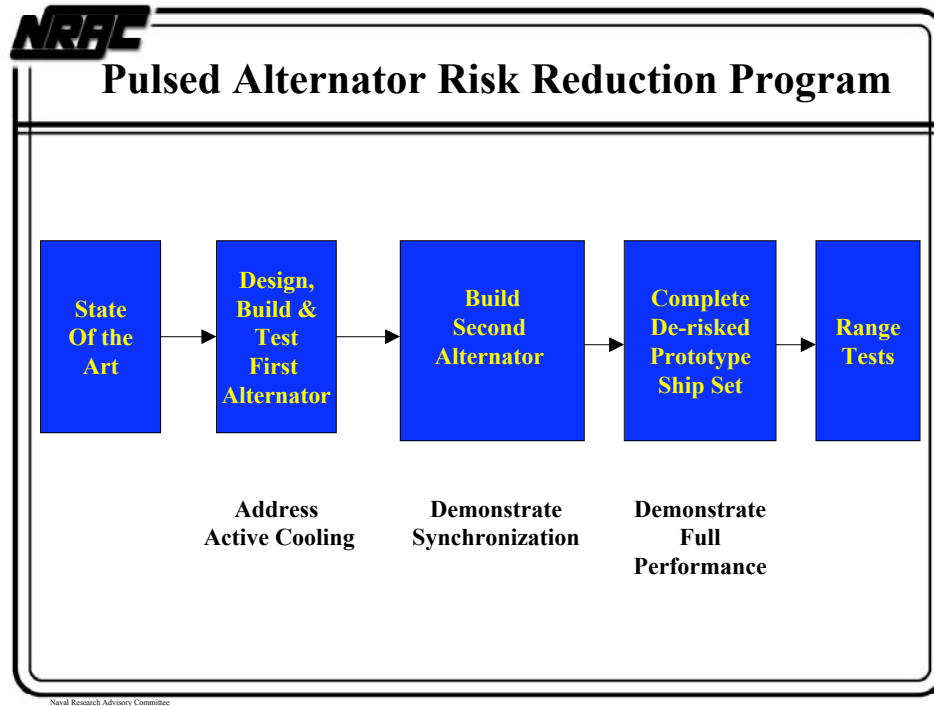
The Army program, which developed the pulsed alternator technology recommended for providing the pulsed power for the Naval railgun, relied on inertial cooling of the alternator windings during burst mode operation. Active cooling of the windings was to be addressed in the next phase of the Army program. The Naval railgun application will require active cooling of the pulsed alternator windings to support the sustained firing rates envisioned and this issue is addressed in the first stage of the recommended development program.

The Army program focused on a direct fire weapon mounted in an armored vehicle, and so requires significantly higher energy and power densities in the pulsed alternator than necessary for the Naval application. Thus the Naval railgun can utilize technology already demonstrated in the Army program to minimize the risk associated with pulsed alternator energy density requirements. Similarly, the use of a modular pulsed power supply design of six to eight alternators would simplify the packaging of the pulsed power supply within the space allocated for the AGS magazines. It would also allow graceful degradation of system performance in the event of component failure while requiring alternators approximately twice the size of the Army design.

One issue that should be addressed early in the development program is the synchronization of multiple alternators during discharge. This requires careful attention to the design of the pulsed power supply control system, but is not anticipated to be a major problem.

Interestingly, the successful reduction of pulsed alternator size and weight in the Army program means that the size and weight of the various auxiliary components required for operation of the power supply will probably exceed the size and weight of the alternators. The system footprint outlined in the proposed program assumes the use of current state of the

art auxiliaries, but significant improvements may be available with modest investment in this area.



A risk reduction program was laid out to address the issues identified for the pulsed alternator. Once a system design is completed, a full-scale, full featured prototype pulsed alternator should be designed, built and tested to address scaling an particularly active cooling of the rotor windings.

Based upon a successful prototype, a second alternator would allow demonstration of synchronization (and the two alternators could be used as a power supply for repetitive fire railgun experiments).

It is the panel's opinion that successful completion of testing with the two pulsed alternators would provide the necessary level of confidence to make a decision to proceed with the full-scale, multi-module pulsed alternator power supply necessary for full-scale demonstration of the Naval railgun.

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Projectile Issues

- **Launch Dynamics**
 - Gee loading
 - EM environment
 - Armature/sabot integration
- **Guidance and Control**
 - GPS/INS accuracy
 - Aero-thermal
- **Also**
 - Lethality
 - Terminal effects
 - Cost per round

Naval Research Advisory Committee

The projectile envisioned for the electromagnetic gun is derived from the HVP development in the Barrage Round Program. That program has already shock tested some guidance, navigation, and control elements to 35 kgee's in addition to actual flight tests at 25kgee's. Also, flechette or preformed fragment dispersal testing was conducted.

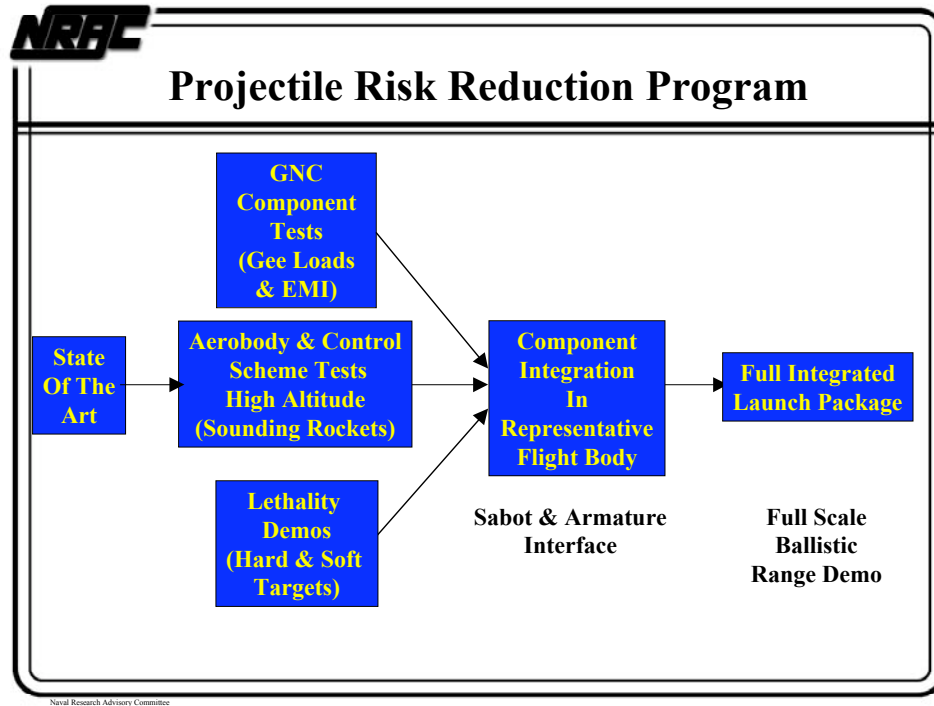
For the railgun, the primary launch dynamic issue is the integrated launch package performance. The performance of the armature, the sabot, and the projectile as one unit within the barrel is crucial as is the survivability of projectile electronics in the high gee/high electromagnetic environment.

Post-launch, ultimate projectile lethality is affected by both guidance and control and aerothermal issues. Key areas under guidance and control are the accuracies of the GPS/INS and the possible degradation of GPS by jamming. Additionally, the use of fins or alternative control mechanisms must be addressed. Concurrently, projectile aerothermal issues include the selection of projectile materials, the thermal loading effects upon the electronics and control components, asymmetric ablation and thermal degradation of the lethal mechanism.

Rounding out the lethality issues are the separation of the warhead fragments in a hypersonic regime and the ultimate lethality of the fragments upon impact. Similarly, if a solid rod is used instead of fragments then its flight stability must be determined.

The panel expects the cost of a round to be about \$10,000.00.

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The risk mitigation development schedule has individual low-cost experiments examining the separate component issues. The control and terminal guidance and lethality evaluations can be modeled and then examined in a series of sounding rocket tests at White Sands Missile Range. These will then be brought together in an integration effort before the full-scale ballistic demonstration of the projectile.

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Railgun Issues

- **Barrel Life**
 - Rail erosion (demonstrated at reduced scale in Army program)
 - 6 MA operation (2 x Army program)
 - Also
 - Active cooling of barrel
 - Launch velocities in excess of 2,500 m/s (Naval goal) achieved at multiple sites in Army program
 - Hypervelocity gouging of rails has been resolved

Naval Research Advisory Committee

Historically, railgun experiments have been directed more toward exploring the limits of performance than toward issues of durability. Three mechanisms have been identified that can cause rail damage. They are:

- 1) Excessive heating of the rail/armature interface in the breech area of the gun where projectile velocity is low.
- 2) Hypervelocity gouging of rails by the passage of the armature (a similar effect has long been observed in rocket sleds).
- 3) Erosion of rails near the muzzle due to failure to maintain galvanic contact between the rails and armature.

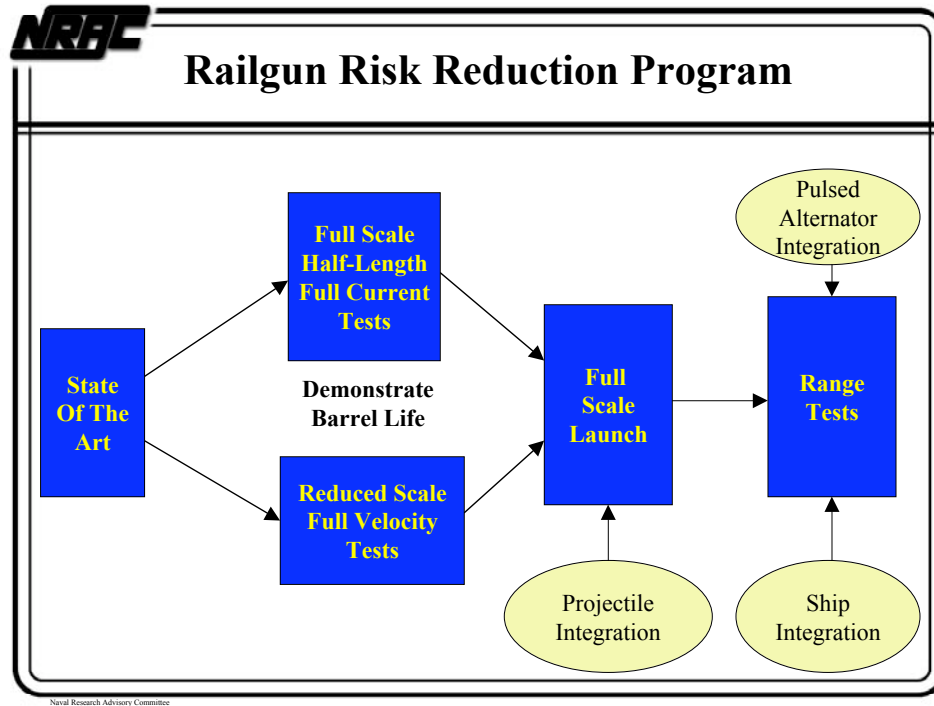
The first issue was addressed in the early 1990s by developing and maintaining sufficient interface pressure between the armature and rails (by both structurally and by magnetic means) to maintain good electrical contact.

The second issue, hypervelocity gouging, has recently been analyzed and modeled. Reduced-scale full velocity experiments have verified that proper material choice can eliminate it.

Detailed, coupled, finite element models including electromagnetic, thermal and mechanical loading of the rails and armature have suggested the approach to solving rail erosion near the muzzle of the railgun. Reduced-scale experiments have shown that structural failure of the armature can be predicted and avoided by proper armature design.

These solutions have not yet been demonstrated at full-scale and at currents applicable to the proposed Navy program.

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As with the pulsed alternators and hypervelocity projectile, a risk reduction program has been designed for the Naval railgun.

A suitable pulsed power supply does not presently exist that will allow all aspects of Naval railgun performance to be demonstrated in a single experiment. In order not to delay such a demonstration, a series of experiments were designed to make use of existing power supplies and facilities.

1) Naval railgun armature designs can first be tested at small scale in any of several existing laboratory facilities (UT-IAT, Army-ARL, etc.).

2) Next, half-scale armature projectile packages can be tested at full velocity (2500 m/s) by making modest upgrades to the Kirkcudbright facility power supply operated by the UK Ministry of Defence.

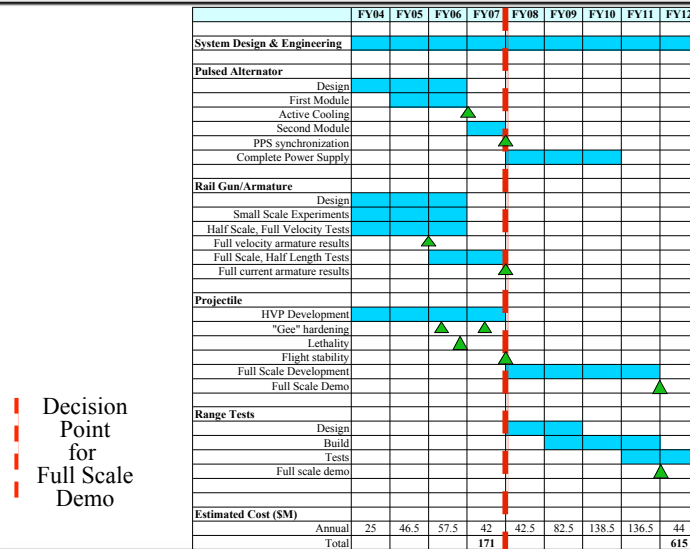
3) Finally, a full-scale, half length Naval railgun barrel armature and projectile design can be tested to full current in at least one existing U.S. facility. This test would allow verification of railgun barrel structural response, current feed into the gun, armature design and projectile response in the high gee, electromagnetic environment.

At this point, the panel feels that the proposed pulsed alternator, projectile and railgun/armature experiments would have addressed all technical issues of concern and provided the information necessary to make an informed decision about commitment to a full-scale demonstration of a Naval railgun.

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Naval Railgun Demonstration Plan



Naval Research Advisory Committee

This plan allows for all remaining, critical railgun risk items to be addressed, through demonstrations and experiments, in the first four years. The funding requirement, approximately \$171M, is considered modest, even trivial, when compared to the potential return on this investment.

After this initial four year phase an informed decision can be made to proceed with a Full Scale Demonstration (launcher, pulsed alternator system, and projectile). This would require approximately another four years and \$445M.

A confluence of factors make this the right time for the Navy to invest in the railgun:

DD(X) will be our first electric warship.

Electromagnetic gun rail problems have been resolved.

We have made considerable progress on the EM Aircraft Launch System (EMALS).

The Marines have well-developed STOM requirements.

We strongly recommend that Navy leadership capitalize on this opportunity to proceed with a program such as this now—in 2004.

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Recommendation

Structure And Fund A Program To Address Critical Issues Preparatory To Demonstrating Full Scale Performance

Naval Research Advisory Committee

In addition to the funding identified above, it is imperative that the Navy make a commitment to this effort and ensure that the responsibility and authority for program execution are appropriately assigned.

We conclude that PMS 405 is uniquely qualified to provide the technical and management leadership required for program success. We strongly recommend that PMS 405 lead the railgun effort.

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ANNEX A

Terms of Reference

Electromagnetic Gun Technology Assessment

Objective

The objectives of this review are to provide a technical assessment of the status of Electromagnetic Gun (EM) technology and the potential for achieving the revolutionary performance associated with this concept for Naval Applications.

Background

The EM Gun offers the potential to achieve extremely high velocity projectile launch capability which, in turn, holds the promise of significantly increased range, and projectile lethality. The potential associated with an EM gun on a Navy Combatant, such as an Electric Warship, and USMC land vehicles is promising enough to warrant consideration for application on the DD(X) (and other future all-electric warships) and future USMC vehicles.

Specific Tasking

This NRAC assessment will accomplish the following:

A. Review and document the performance capabilities considered necessary to achieve a militarily effective EM Gun system. At a minimum include projectile mass, velocities, and rate of fire required to achieve required lethality and range capabilities. Discuss the foundations on which these criteria are based and the efforts necessary to ensure confidence in same (ie the extent to which theory has been or will be validated by experiments and testing).

B. Review and assess the currently demonstrated and projected performance of those technologies necessary to field a durable EM gun with predictable, repeatable performance that satisfies the criteria identified in (a). Identify the technology barriers that may impede achieving these criteria; the adequacy of these efforts, potential work-arounds, and other factors that may reduce risk, schedule, and cost.

C. The assessment should evaluate the ability to produce a projectile with electronic systems that service and perform effectively the launch environment – loads, EMI, magnetic fields, etc. – as well as performing throughout the flight to target.

D. Rough order of magnitude cost estimates for the non-recurring general projectile development program and the recurring projectile cost should be projected if possible.

Provide a status report on findings to ASN (RDA) on 1 August 2003.

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APPENDIX B

BRIEFINGS

Navy EM Gun Vision
Dahlgren EM Gun Technology
Dahlgren Projectile Technology
CEM Brief on Power Supply Technology
Acquisition Perspective
IPS
CNA EM Gun Study
Sandia Brief on Capacitors and Coil Guns
ONR 33 Brief
ONR 35 Brief
Army EM Gun Study
Army EM Gun Armatures
Army Projectile Forces
IAT on Armatures and Barrel Life
ONI Brief on EM Guns Outside U.S.
CEM Armature Information
Industry Perspective – UDLF
Industry Perspective – Lockheed Martin
DARPA Update
Marine Corps Background

VISITS

UK EM Gun Program	Kirkcudbright, Scotland
EM Gun Discussions	London, England

APPENDIX C

ACRONYMS

AGS	Advanced Gun System
ARL	Army Research Laboratory
CNA	Center for Naval Analysis
CIWS	Close in Weapons System
DARPA	Defense Advanced Research Projects Agency
DD(X)	Future Destroyer
EM	Electromagnetic
EMALS	Electromagnetic Aircraft Launch System
EMI	Electromagnetic Interference
ERGM	Extended Range Guided Munition
ESD	Electrostatic Discharge
GEE	G-Force (acceleration due to earth's gravity)
GNC	Guidance, Navigation, and Control
GPS/INS	Global Positioning System/Inertial Navigation System
HERO	Hazards of Electromagnetic Radiation to Ordnance
HVP	Hypervelocity Projectile
IAT	Institute for Advanced Technology
IPS	Integrated Propulsion System
IRT	Independent Review Team
J/G	Joules per gram
KG	Kilogram
KGEE	Kilogee
KM/SEC	Kilometers per second
LRLAP	Long Range Land Attack Projectile

MJ	Mega-joule
MCCDC	Marine Corps Combat Development Command
MRAAS	Multi-Role Armament and Ammunition System
MRSI	Multiple Round Simultaneous Impact
MW	Megawatt
NAVSEA	Naval Sea Systems Command
NM	Nautical Mile
NRAC	Naval Research Advisory Committee
NSFS	Naval Surface Fire Support
NSWC	Naval Surface Warfare Center
ONI	Office of Naval Intelligence
ONR	Office of Naval Research
PEO	Program Executive Office
PMS	Program Manager Ships
ROM	Rough Order of Magnitude
SDIO/MDA	Strategic Defense Initiative Organization/Model Driven Architecture
SPAWAR	Space and Naval Warfare Command
STOM	Ship to Objective Maneuver
TOF	Time of Flight
UAV	Unmanned Aerial Vehicle